(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 546 706 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
13.03.1996 Bulletin 1996/11

(51) Int Cl.6: H01S 3/06, H01S 3/19, H04B 10/00

(21) Application number: 92310602.5

(22) Date of filing: 20.11.1992

(54) **Article comprising a DFB semiconductor laser**

Gegenstand der einen DFB-Halbleiterlaser enthält

Article comprenant un laser DFB à semi-conducteur

(84) Designated Contracting States:
DE FR GB

(30) Priority: 12.12.1991 US 806969

(43) Date of publication of application:
16.06.1993 Bulletin 1993/24

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(56) References cited:
EP-A- 0 533 485
FR-A- 2 647 276
US-A- 5 023 198

- PATENT ABSTRACTS OF JAPAN vol. 10, no. 329 (E-452)(2385) 8 November 1986;& JP-A-61134096
- PATENT ABSTRACTS OF JAPAN vol. 12, no. 414 (E-677)(3261) 2 November 1988;& JP-A-63153884
- PATENT ABSTRACTS OF JAPAN vol. 11, no. 257 (E-524)(2704) 20 August 1987;& JP-A-62065490
- PATENT ABSTRACTS OF JAPAN vol. 14, no. 82 (E-889)(4025) 15 February 1990;& JP-A-01293688

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410

Description

Field of the Invention

This application pertains to semiconductor lasers that comprise a "grating" structure. All such laser types are herein collectively designated as distributed feedback (DFB) lasers.

Background of the Invention

It is well known that DFB semiconductor lasers can have many advantageous features (e.g., extremely narrow-band emission) that make them desirable for, inter alia, optical fiber communications. However, there generally are at present two major technological problems in the manufacture of such lasers. One is the reproducible control of the optical feedback coupling coefficient κ, and the other is the discrimination of one definite oscillation wavelength out of the two possible oscillations at the edges of the Bragg reflection band.

The former problem is known to have a very significant effect on laser characteristics, e.g., spectral linewidth, harmonic distortion, and intensity noise, and thus can seriously affect manufacturing yield. The latter, if uncontrolled, can substantially reduce the fraction of devices having a specified wavelength, and thus also affects manufacturing yield.

One known approach to addressing the oscillation wavelength degeneracy problem in index-coupled DFB lasers is the use of antireflection/high reflectivity (AR/HR)-coated facets. This, however, can also cause a yield problem due to the phase uncertainty at the facets. Another approach is the incorporation of a $\lambda/4$ or corrugation pitch modulated phase shift. For perfect AR coatings, DFB lasers could in principle be produced with high yield, but the yield deteriorates rapidly for (typically encountered) reflectivities of a few percent. Furthermore, such lasers waste substantially half of the power by emission through the back facet, and can exhibit high spatial hole burning, which typically gives rise to optical non-linearity in the light-current curves, increased spectral linewidth, and a less flat frequency modulation response.

An alternative approach to the wavelength degeneracy problem is the introduction of gain coupling. See H. Kogelnik et al., Journal of Applied Physics, Vol. 43, p. 2327 (1972). Theory predicts that a purely gain coupled laser should have one lasing mode exactly at the Bragg wavelength for AR-coated facets (thereby solving the degeneracy problem), and that even a small degree of gain coupling can be advantageous for both AR-coated and non-AR-coated lasers. The validity of the gain-coupled approach has recently been demonstrated in GaAs/AlGaAs DFB lasers. See Y. Luo et al., Applied Physics Letters, Vol. 56(17), p. 1620 (1990); Y. Luo et al., IEEE Journal of Quantum Electronics, Vol. 27(6), p. 1724 (1991). These papers disclose a DFB laser comprising an active layer of periodically varying thickness. This is achieved through etching of a conventional grating of period Λ into the surface of an appropriate multi-layer semiconductor body, growing a buffer layer over the grating such that the exposed buffer layer surface is corrugated (with period Λ), and growing the active layer on the exposed corrugated buffer layer surface such that the active layer surface is flat. This clearly is a complicated procedure that cannot easily be incorporated into a manufacturing process. See also T. Inoue et al., IEEE Transactions Photonics Technology Letters, Vol. 3(11), p. 958 (1991), which also discloses a gain coupled DFB laser with a corrugated active layer.

Patent Abstracts of Japan, Vol. 14, No. 82 (E-889), February 15, 1990 (JP-A-1 293 688), discloses a GaAs-based DFB laser that comprises a multi-layer grating region, with some of the layers segmented to form the grating, and the remainder of the layers being unsegmented. JP-A-62 065 490 discloses another semiconductor laser with a multi-layer grating region.

A different approach is disclosed in B. Borchert et al., IEEE Transactions Photonics Technology Letters, Vol. 3(11), p. 955 (1991) and Y. Nakano et al., Applied Physics Letters, Vol. 55(16), p. 1606 (1989). Both papers disclose gain-coupled DFB lasers comprising a periodic loss structure that is spaced apart from the active region of the laser.

Although there are now known techniques that address at least one of the above referred-to two problems, the techniques generally are complicated and/or not fully effective. For instance, the gain-coupled DFB lasers of the two last cited papers have relatively complex structures that address only the mode degeneracy problem but do not address the coupling constant control problem.

In view of the importance of increasing the manufacturing yield of acceptable DFB lasers it would be very desirable to have available a simple laser design that can reliably overcome the above referred-to two problems. This application discloses such a design.

Brief Description of the Drawings

FIG. 1 schematically depicts relevant aspects of an exemplary embodiment of the invention;

FIGs. 2-4 give data on output power vs. drive current, output intensity vs. wavelength, and side mode suppression ratio vs. drive current, respectively, all for an exemplary laser according to the invention; and

FIGs. 5 schematically depicts a further exemplary embodiment of the invention.

Glossary

A "quantum well" herein is a thin semiconductor region of first composition and thickness t, sandwiched between semiconductor material of a second composition,

with the compositions selected such that the relevant bandgap energy E_{g1} of the first composition is less than the bandgap energy E_{g2} of the second composition, and t furthermore is selected such that free carriers in the quantum well exhibit quantum effects, e.g., the lowest bound energy level associated with the well does not coincide with the relevant band edge of the well material. Typically, t is less than about 30 nm.

The Invention

The invention is as defined by the claims. In a broad aspect the invention is an article (e.g., an optical fiber transmitter or transceiver, or an optical fiber communication system that comprises such a transmitter or receiver) that comprises a novel DFB semiconductor laser having features that, inter alia, can result in substantially improved laser manufacturing yield.

More particularly, the inventive DFB laser comprises a semiconductor body that comprises a multiplicity of epitaxial semiconductor layers on a semiconductor substrate. The semiconductor body comprises a periodically varying first region (the "grating" region) having a period Λ (in the longitudinal direction associated with the laser), and further comprises a second region (the "active" region) that is adapted for generation of electromagnetic radiation of a predetermined wavelength λ through electron-hole recombination and optical interaction with the grating. The active region is spaced apart from the grating region. The laser further comprises contact means that facilitate flowing an electrical current through the semiconductor body.

Significantly, in a laser according to the invention the grating region comprises one or more longitudinally varying (e.g., patterned) thin semiconductor layers of a first semiconductor composition, with a given first composition layer sandwiched between semiconductor material of a second composition. The first composition layers will be referred to herein as "quantum wells" or "QWs", although practice of the invention does not require that the layer thickness be such that the first composition layers exhibit the above described characteristics of a quantum well.

Each QW in the grating region is divided into separate segments, with every segment measuring less than Λ in the longitudinal direction. The spacing between the active region and the grating region is such that, during normal lasing operation, radiation of wavelength λ can interact with the grating.

FIG. 1 schematically depicts relevant aspects of an exemplary laser according to the invention. On substrate 11 (e.g., n^+ InP) are disposed QWs 121 and 122 (e.g., n - $In_yGa_{1-y}As$, for all values of y referred to collectively as InGaAs), with barrier layer 131 (e.g., n - InP) therebetween. Advantageously, the QW structure is formed such that the top layer (132) has the barrier layer composition, with the barrier layer composition selected to be substantially the same as that of the immediately adjacent substrate material (excluding possible differences in doping level; an optional buffer layer or layers would, for purposes of this discussion, be considered to be part of the substrate).

The surface of the described multilayer structure is patterned by known means such that a Bragg grating of period Λ is formed, with the grating advantageously extending below the lowest QW layer. It is to be noted that in preferred embodiments the thus created corrugated surface 14 consists primarily of material of one composition (exemplarily InP), with only a minor amount of material of different composition (exemplarily InGaAs) exposed. This relative homogeneity of the surface facilitates growth of high quality epitaxial material of the same composition thereon, as will be appreciated by those skilled in the art.

On surface 14 is grown spacer layer 15 (e.g., n-InP), advantageously completely covering surface 14. On the spacer layer is disposed waveguide layer 16 (e.g., InGaAsP), followed by the active region that consists of a multiplicity of QWs 17 (e.g., $In_xGa_{1-x}As$; x not necessarily different from y), with barrier layers 18 (e.g., InGaAsP) therebetween. This is followed by waveguide layer 19 (e.g., InGaAsP), cladding layer 20 (e.g., p-InP), and cap layer 21 (e.g., p^+ InGaAsP). Contacts can be conventional and are not shown.

It will be understood that, except for the novel grating structure that comprises a QW (or QWs), lasers according to the invention can have conventional structure. The invention clearly applies to substantially all types of semiconductor DFB lasers, and is not limited to use in multi-quantum well DFB lasers. As those skilled in the art will have recognized, the invention can be embodied in DFB lasers wherein the grating is "below" the active region, as shown in FIG. 1, in lasers wherein it is "above" the active region, as well as in so-called "Distributed Bragg Reflector" (DBR) lasers in which the grating structure is laterally connected to the active region by an optical waveguide. The grating QWs optionally can be spaced such that the QWs are coupled, i.e., form a "superlattice". Herein we do not distinguish between coupled or not-coupled multi-QW structures, referring to them collectively as QW structures.

Use of the novel grating structure in a DFB laser can offer many advantages. For instance, because the QWs are thin, and preferably interleaved and capped with material that has substantially the same composition as the spacer layer and immediately adjacent substrate material, growth of the spacer layer over the grating surface is substantially an instance of homoepitaxial growth. This typically makes the epitaxial growth over the grating a trivial task, and can virtually insure freedom from defects. Furthermore, the coupling constant κ typically can be conveniently controlled through appropriate choice of the number, composition and/or thickness of the QWs. The depth profile of the grating typically can be tailored by appropriate variation of QW composition and/or thickness, and/or barrier layer composition and/or thickness.

Thus, I contemplate embodiments of my invention wherein the grating QWs are not all of the same thickness or composition, and/or wherein the grating barrier layers are not all of the same thickness or composition.

It is known that, for optimal laser performance, the quantity κL (where L is the cavity length) typically should be in the range 1-2. Thus, in many cases κ desirably is quite small, attainable with just one or a few grating QWs. This in turn makes it possible to have gratings wherein all QWs are etched through, substantially as shown in FIG. 1. In such (preferred) lasers the actual grating depth plays no significant role in affecting κ, contrary to the situation that obtains in conventional DFB lasers. Thus, it is typically a relatively simple matter to control κ in preferred lasers according to the invention.

Other advantageous features of lasers according to the invention are as follows. Because of the well-known quantum size effect in QWs, the grating QWs can be designed such that the absorption edge of the grating QWs is above the lasing wavelength, even if the same material composition is used in the active layer of the laser and in the grating QWs, thus simplifying manufacture. It will he noted that the resulting DFB laser is an index-coupled laser, and it may bear emphasizing that the instant invention can be embodied in index-coupled as well as in gain (loss)-coupled lasers, as well as in lasers that exhibit a combination of both these coupling mechanisms.

If a gain (loss)-coupled grating is desired, then the thickness and/or composition of the grating QWs can be selected such that the QW absorption edge is below the lasing wavelength. By making the grating QWs very thin the gain-coupling coupling effect can be made to dominate over the index-coupling effect. If desired, the grating QWs can have a composition with narrower bulk bandgap than the relevant active region material. The grating QW composition can be selected such that the QWs are strained, either in tension or in compression. Those skilled in the art will appreciate that use of strained QWs can be used to modify the respective coupling coefficients of the TE and TM modes of a DFB laser according to the invention, thereby giving the device designer an additional degree of freedom.

The above discussion shows that the use of QWs in the grating region can greatly facilitate, inter alia, the reproducible re-growth of the grating and the control of the coupling coefficient. It can also provide a very convenient and effective scheme for achieving gain-coupled DFB lasers, and thus for removing the wavelength degeneracy.

A laser substantially as shown in FIG. 1 was made as follows. Two 4 nm thick n- $In_{0.62}$ $Ga_{0.38}$ As layers, respectively separated and capped by 9.3 nm thick n-InP layers, were grown on a conventional (100) oriented 5 cm diameter n+ InP substrate by conventional chemical beam epitaxy (CBE) at 545°C. First order gratings (Λ = 240 nm) were prepared by conventional holographic techniques and wet etching. The grating depth was about 48 nm. After standard cleaning the wafer was re-introduced into the CBE system, and heated to about 545°C under P overpressure from pre-cracked PH_3. Under these conditions no observable grating erosion occurred. An n- InP spacer layer of thickness 65 nm (measured from the top of the grating) was grown, followed by growth of a standard strained-layer 6-QW separate confinement heterostructure (SCH). The quaternary ($Q_{1.25}$) waveguide layers were 52.2 nm thick, the $In_{0.6}$ $Ga_{0.4}$ As QWs and Q_{1-25} barrier layers were 5 nm and 18.6 nm, respectively. The wafer was then further conventionally processed into buried heterostructure lasers, including MO-VPE re-growth of Fe-doped InP at 630°C. Diethylzinc and tetraethyltin were employed as the p- and n-type doping sources, respectively.

FIG. 2 shows exemplary data on laser output vs. drive current, FIG. 3 shows the lasing spectrum of the same laser, and FIG. 4 shows data on the side-mode-suppression-ratio (SMSR) vs. drive current, all for a 0.5 mm cavity length 2QW-grating laser produced substantially as described above, with (5%) AR-coating on both facets. AR coating is optional, and even as-cleaved lasers according to the invention can show high SMSR.

FIG. 5 schematically depicts a further exemplary embodiment of the invention. On corrugated surface 14 is grown cladding layer 41 (e.g., n-InP), active layer 42 (e.g., InGaAsP), cladding layer 43 (e.g., p-InP), and cap layer 21 (e.g., p+-InGaAs).

Claims

1. An article comprising a DFB laser that comprises a semiconductor body comprising a multiplicity of epitaxial semiconductor layers on a semiconductor substrate (11) comprising:

   a) a periodically varying semiconductor grating region, associated with the grating region being a period Λ and

   b) a semiconductor active region adapted for generation of electromagnetic radiation of wavelength λ through electron-hole recombination therein, the active region being spaced apart from the grating region; and

   c) the laser further comprises contact means that facilitate flowing an electrical current through said semiconductor body; associated with the laser being a longitudinal direction; wherein

   d) the grating region comprises a multiplicity of semiconductor quantum well layers (121,122) of a first composition, a given first composition well layer being sandwiched between semiconductor material of a second composition (11,131) and varying in the longitudinal direction with period Λ and the top layer (132) of the grating region being material of the second composition;

e) the grating region is patterned such that all first composition well layers (121,122) in the grating region are divided into segments of length less than period Λ in the longitudinal direction;

CHARACTERIZED IN THAT

f) the grating region is directly or by means of one or more buffer layers disposed on the substrate, with the buffer layer or the substrate immediately adjacent to the grating region being made from semiconductor material of the second composition; and

g) a second composition semiconductor layer (15) is disposed on the patterned grating region.

2. The article according to claim 1, wherein the first and second compositions are InGaAs and InP, respectively.

3. The article according to claim 2, wherein a given first composition quantum well layer has a thickness less than 30 nm.

Patentansprüche

1. Gegenstand mit einem DFB-Laser, der einen Halbleiterkörper mit einer Vielzahl von epitaxialen Halbleiterschichten an seinem Halbleitersubstrat (11) umfaßt, mit:

a) einem sich periodisch ändernden Halbleitergitterbereich, wobei dem Gitterbereich eine Periode Λ zugeordnet ist, und

b) einem aktiven Halbleiterbereich zur Erzeugung von elektromagnetischer Strahlung der Wellenlänge λ durch Elektronen-Loch-Rekombination in diesem, wobei der aktive Bereich von dem Gitterbereich beabstandet ist, und

c) wobei der Laser ferner eine Kontakteinrichtung umfaßt, die das Fließen eines elektrischen Stroms durch den Halbleiterkörper unterstützt, wobei dem Laser eine Längsrichtung zugeordnet ist, bei welchem

d) der Gitterbereich eine Vielzahl von Halbleiterquantenmuldenschichten (121, 122) mit einer ersten Zusammensetzung umfaßt, wobei eine gegebene Quantenmuldenschicht mit der ersten Zusammensetzung sandwichartige zwischen Halbleitermaterial einer zweiten Zusammensetzung (11, 131) angeordnet ist und sich in der Längsrichtung mit der Periode Λ ändert und die obere Schicht (132) des Gitterbereichs Material der zweiten Zusammensetzung ist,

e) der Gitterbereich so strukturiert ist, daß alle Muldenschichten mit der ersten Zusammensetzung (121, 122) im Gitterbereich in Abschnitte mit kleineren Längen als die Periode Λ in Längsrichtung geteilt sind,

dadurch gekennzeichnet, daß

f) der Gitterbereich direkt oder mittels einer oder mehrerer Pufferschichten an dem Substrat angeordnet ist, wobei die Pufferschicht oder das Substrat dem aus Halbleitermaterial der zweiten Zusammensetzung hergestellten Gitterbereich unmittelbar benachbart ist, und

g) eine Halbleiterschicht (15) mit der zweiten Zusammensetzung an dem strukturierten Gitterbereich angeordnet ist.

2. Gegenstand nach Anspruch 1, bei welchem die erste und die zweite Zusammensetzung jeweils InGaAs und InP sind.

3. Gegenstand nach Anspruch 2, bei welchem eine Quantenmuldenschicht mit der gegebenen ersten Zusammensetzung eine Dicke von weniger als 30 nm hat.

Revendications

1. Article comprenant un laser DFB qui comprend un corps semi-conducteur comportant une multiplicité de couches semi-conductrices épitaxiales sur un substrat semi-conducteur (11), comprenant :

a) une région à réseau de diffraction semi-conducteur variant périodiquement, associée à la région de réseau de diffraction de période Λ, et

b) une région semi-conductrice active conçue pour produire un rayonnement électromagnétique de longueur d'onde λ par recombinaison d'électrons et de trous dans celle-ci, la région active étant à distance de la région à réseau de diffraction; et

c) le laser comprenant en outre un moyen de contact qui facilite le passage d'un courant électrique à travers le corps semi-conducteur; associé au fait que l'effet laser est produit dans une direction longitudinale; dans lequel

d) la région à réseau de diffraction comprend une multiplicité de couches à puits quantiques semiconducteurs (121, 122) ayant une première composition, une couche particulière de puits ayant une première composition étant intercalée dans un matériau semi-conducteur ayant une seconde composition (11, 131) et variant dans la direction longitudinale avec une période Λ, et la couche supérieure (132) de la région à réseau de diffraction étant constituée d'un matériau ayant la seconde composition;

e) la région à réseau de diffraction est soumise à la formation d'un motif de telle façon que tou-

tes les couches de puits ayant la première composition (121, 122) dans la région à réseau de diffraction, soient divisées en segments ayant une longueur inférieure à la période Λ dans la direction longitudinale;

caractérisé en ce que

f) la région à réseau de diffraction est disposée directement, ou par l'intermédiaire d'une ou plusieurs couches tampons, sur le substrat, la couche tampon ou le substrat, au voisinage immédiat de la région à réseau de diffraction, étant constitué d'un matériau semi-conducteur ayant la seconde composition; et

g) une couche semi-conductrice ayant une seconde composition (15) est disposée sur la région à réseau de diffraction en forme de motif.

2. Article selon la revendication 1, dans lequel les première et seconde compositions sont respectivement l'InGaAs et l'InP.

3. Article selon la revendication 2, dans lequel une couche donnée de puits quantique ayant la première composition a une épaisseur inférieure à 30 nm.

FIG. 1

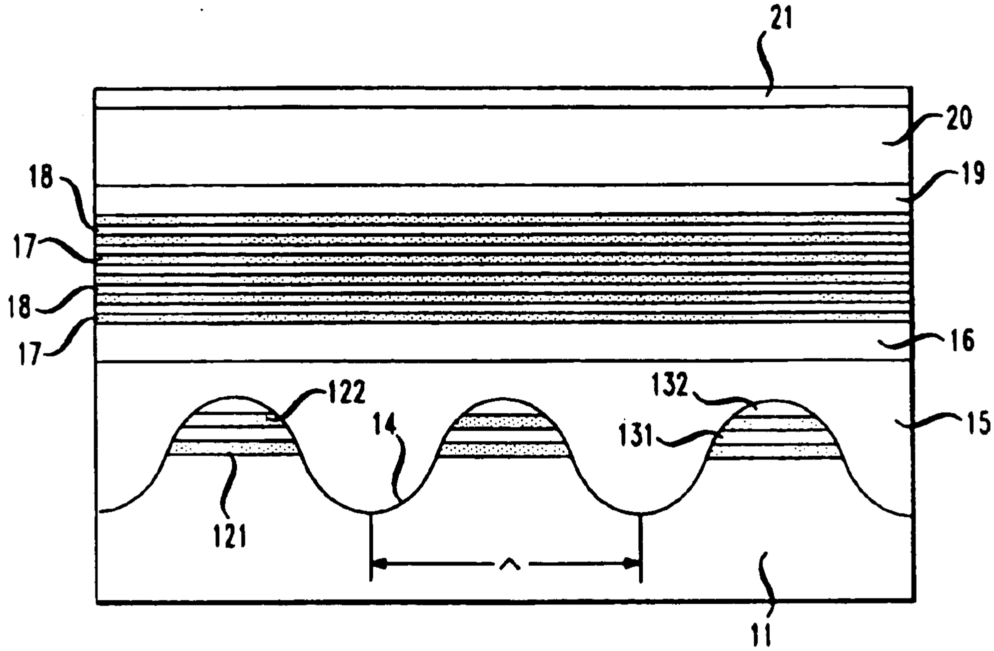
21
20
19
18
17
18
17
16
122
14
132
131
15
121
^
11

FIG. 2

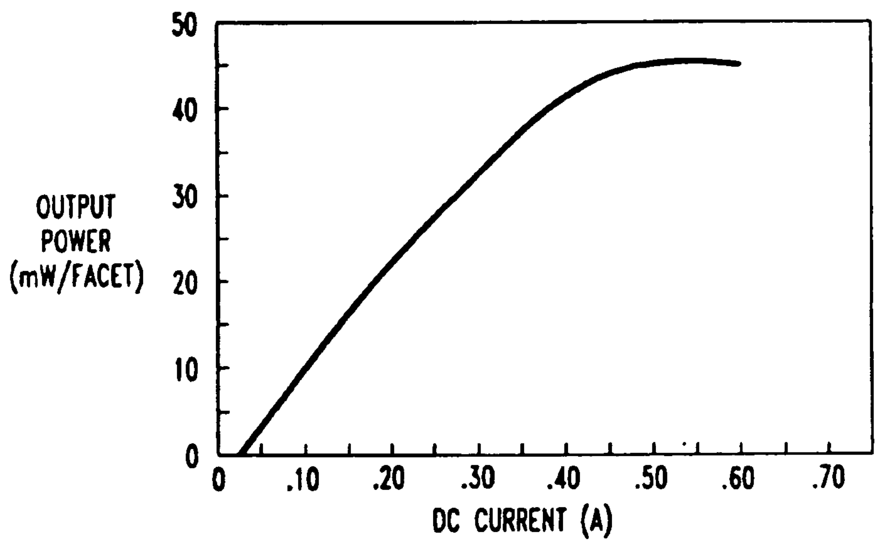
OUTPUT POWER (mW/FACET)
50
40
30
20
10
0
0
.10
.20
.30
.40
.50
.60
.70
DC CURRENT (A)

FIG. 3

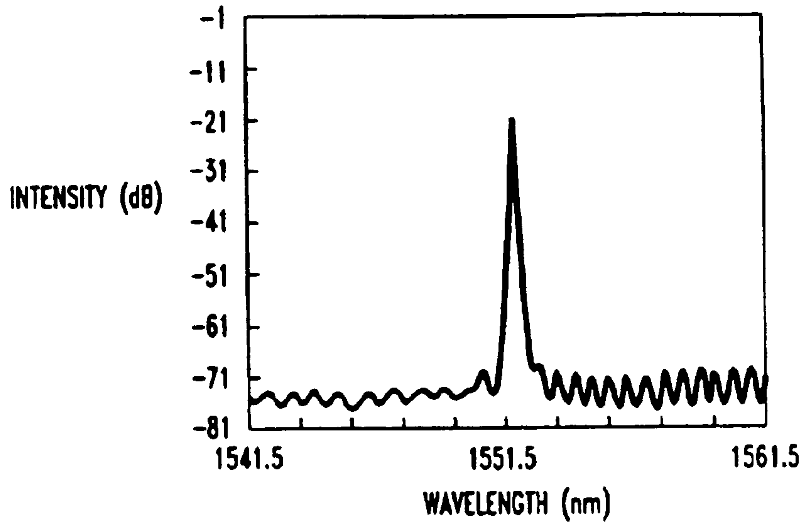
-1
-11
-21
-31
-41
-51
-61
-71
-81
INTENSITY (dB)
1541.5
1551.5
1561.5
WAVELENGTH (nm)

FIG. 4

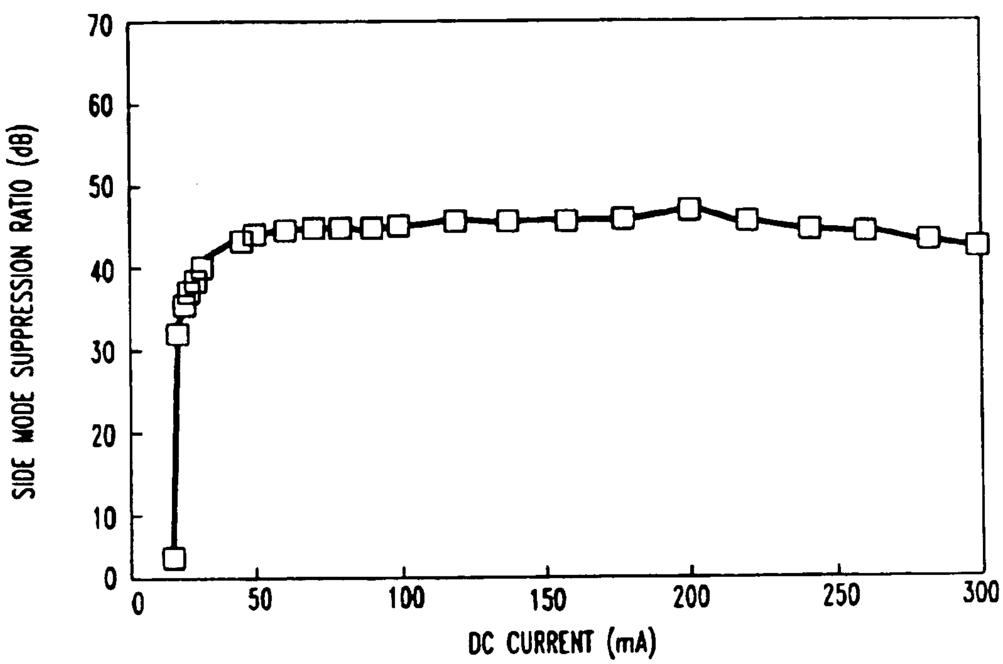
70
60
50
40
30
20
10
0
SIDE MODE SUPPRESSION RATIO (dB)
0
50
100
150
200
250
300
DC CURRENT (mA)

FIG. 5